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# THE EFFECT OF THE NATURE OF THE DISCHARGE UPON THE SPARK SPECTRUM

by

HENRY WILLIAM KIRCHER

A Thesis Submitted for the Degree of

Master of Philosophy

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It is my purpose in this thesis to discuss the source of luminosity in the electric spark and to consider the bearing of various electrical conditions such as frequency, potential-gradient, current density and form of discgarge curve upon the character of the spark and its spectrum.

The subject for convenience of treatment, will be arranged in three parts; the first dealing with the period and form of discharge curve in an oscillatory circuit containing a spark gap,; The second with the cause of luminosity in the spark and the third with the widening of the lines in the spectrum of the spark. These three subjects being very closely related the same experimental data often often bear directly on two or even all three of them, but for the sake of avoiding repetition it will be given only under the topics with which it is most closely connected.

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## The Period and Character of Discharge Current.

That the nature and intensity of the light emitted by the spark in an oscillatory discharge depends upon the electrical constants of the circuit is well known. It is my purpose here to study the period of an oscillatory circuit containing a spark and to try and conclude something about the form of discharge current under different electrical conditions, from the appearance of photographs of the spark in an oscillatory circuit. The theoretical value for the period in a metalic circuit containing capacity, self-induction and resistance according to W Thomson[1] is given by the formula $T = \frac{2\pi}{\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}}$ which in case the resistance is small reduces to $T = 2\pi\sqrt{LC}$. The latter formula is generally used to calculate the period of a circuit with a spark gap for the resistance in such a circuit is not known.

Two experimental methods have been devised for ascertaining the period. In one oscillations of the spark are photographed by means of a rapidly rotating mirror.

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I, Phil. Mag. 5, P. 393, 1853.

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In the other the charge on the condenser at successive intervals is measured. The first method which is due to Feddersen[1] complicates the circuit by the introduction of a spark gap and we can not say apriori that the spark does not effect the period of the circuit. The following experiments show that if only such photographs are used as have a uniform distribution of the successive oscellations, the period closely approximates that of a metalic circuit. The general run of photographs however show that the values of the period obtained by photographic method often vary very much from those calculated for the circuit and this variation seems to be a function of the spark.

Unfortunately about half of the experiments in which the experimental value of the period, obtained by photographing the spark, is compared with the value calculated by means of Thomson's formula can not be relied upon as being accurate because the exact values of the electrical constants of the circuit were not determined. Thus Feddersen in the experiments referred to above, obtained many

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I, Pogg. Ann. I03, P. 69, I858; I08, P. 49I, I859;II3,P. 437, I86I.

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good photographs of the oscillatory discharge but since he did not know the exact values of the constants of his circuit his photographs are only of interest in so far as they illustrate that an increase in the capacity causes the oscillations on the photographic plates to become sharp and distinct while an increase of self-induction causes them to become diffuse and to merge into one another.

Lorenz repeated Feddersen's experiments with more careful measurements of the capacity and found that the observed observed values agreed quite well with those calculated. Though the calculated and observed values in his experiments were of the same magnitude, Lorenz found t that the period as calculated by means of the formula was always longer than that observed. He thinks that since his capacity was measured at low frequencies it was very likely smaller for high frequencies which would account for the descrepency. this is no doubt true but since we have no means of knowing how the capacity depends upon the frequency we can not draw any definite conclusions from this data

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I, Wied. Ann. 7, P. I6I, I879.

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as to the actual relation between the observed and calculated period. Boys[1] like Lorenz used a glass condenser and got results that varied from two to six per cent from the calculated period. The general average for the calculated period being about three per cent greater than the observed. He also remarks that his capacity being calculated for low frequencies would be less for high frequencies and would thus account for the disagreement. On the other hand, Misler[2] with a capacity consisting of Lyden jars calibrated by means of a standard capacity obtained experimental values for the period that were on the averagetwo per cent greater than the calculated. This however is only true when the so-called good results are taken; in other cases the observed value is often twenty per cent greater than the calculatedand in several instances it is fifty per cent greater. The observed period in these cases only agrees with the calculated when the dark spaces between the bright lines are taken as representing the distance between oscillations.

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I, Phil. Mag. 30, P. 248, I890.

2, Wien. Ber. 94, P. 579, I890.

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More reliable results on the comparison of theoretical with experimental value for the period are those of Trowbridge and Sabine[1]. They eliminated the uncertainty of the capacity by using an air condenser for which they could easily calculate the capacity. The periods measured by them were in the neighborhood of $3 \times 10^{-6}$ and though they agree quite well with the calculated period they are always somewhat longer, averaging about three per cent longer. Besides having a somewhat longer period the discharge generally shows a periodic fluctuation of the period during the discharge. Regarding this fluctuation they say, "The electrical oscillations in the air between the plates of an air condenser show a periodicity extending through the entire range of oscillations. We believe that this periodicy is the analogue of the phenomenon of hysteresis in magnetism. A certain amount of energy of the electrical discharge is spent in overcoming the dielectric viscosity of the air and in straining the air dielectric. The strain is not immediately released in unison with the electrical surgings."

I do not see how such a strain could occur in a

I, Phil. Mag. 30, P. 323, 1890.

dialectric that would be periodic and have a period of about four times that of the corcuit. If there is a strain we should expect it to be renewed at avery surge. Farther they show that the periods of successive oscellations do not agree with each other.but often differ by as much as eight or ten per cent and that the period if calculated from the discharge at one electrode does not agree within several per cent of that calculated from the discharges of the other. In their work on the experimental determination of the velocity of electric waves in a metalic circuit Trowbridge and Duane[1] find a great irregularity between the successive oscellations and that the period if calculated from the first few oscillations is much too large. The y offer as an explaination for the long period indicated by the first few oscillations an interdependence of the secondary and primary circuit which on account of the large dampingcoefficient of the secondary is very marked during the first oscillations. This however does not explain the irregularaties that occur near the middle and toward the end of the discharge.

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I, Phil. Mag. 90, P. 2II, 1895.

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The latest and most complete comparison of the theoretical and experimental values of the period is made by Battelli and Magri[1]. They took great pains in determining the values of the constants L, R, and C, of the circuit and had an efficient means of photographing the spark. Their capacity consisted of a carefully constructed air condenser. They photographed various periods the shortest being about $7 \times 10^{-7}$ seconds. The experimental values for the period were six or even eight per cent from the theoretical: the large variations always indicating a shorter calculated than observed period and the general average being about two and one half per cent greater than the calculated. In remarking upon the irregularity of the oscillations as shown by the photographs they say. "If the spark is produced between rather volatile electrodes as for instance, cadmium electrodes, its behavior is very regular. If the electrodes of platinum or platinum-iridium the spark as a rule shows a very irregular aspect as that of photograph number two of the above mentioned plate, where noticable displacements

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I, Phil. Mag. Vol. 5, Series 6, P.I, 620.

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between the single partial sparks are to be observed each of which so to speak has to open a discharge way of its own".

They think that this displacement between the images of successive oscillations is due to the fact that the spark does not always follow the same path. In order to eliminate the error that might be introduced by this irregularity they chose from many plates only such as show a uniform distribution of the oscillations. The second method of determining the period since it deals with a purely metalic circuit does not throw much light upon the character of the spark discharge but in order to compare the two methods I will give the results obtained by Webster[1]. The circuit used by Webster was so arranged that it could be made and broken at definite intervals by means of a falling weight. He was thus able to measure the charge upon the condenser at different intervalsand from the values of these charges obtain the period. Although he does not reach as high frequencies as are reached by the other method he obtains results that seldom vary more than one tenth of a

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I, Phys. Rev. XI, P. 297, 1898.

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per cent from the theoretical period and average to within one fiftieth of a percent of that value. When we compare the results obtained by the latter method with those of the former we notice that they are far more compatable and reliable and the question arises, why the greater efficiency of the latter method? Since the dependence of the last results upon mechanical appliances is if anything greater than the former, we must conclude that the trouble is due to the introduction of a spark-gap. The fact pointed out by Bettelli and M agri that successive discharges in the spark do not always follow the same path may easily accuont for the irregular distribution of the successive images upon the photographic plate. For a displacement of one millimeter might easily occur between the paths of two successive oscillations. The way to remedy this difficulty would be to increase the speed of the image so that the distance between successive images of the oscillations would be great compared with any displacement that would occur.

In cases where air condensers were used whose capacity very likely remained constant for all frequencies the average observed period is always from two to three percent

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longer than the calculated and all the large variations that occur, sometimes so large as to almost double the period, are on the side of a longer observed period. this indicates that the tendency of the spark is to increase the time of os cillation. In the spark-gap where the current ceases between every elementary discharge we must concede that during such period however short it may be the resistance of the gap rises and approximates the condition which exists between the separate groups of discharges. Thus as Battelli and Magri observe, each discharge would be compelled to open a path of its own which would not only cause an irregularity in the photographic image of the oscillations but would lengthen the period in somewhat the same way as holding a pendulum for an instant when it is at its greatest amplitude would lengthen its period.

The great irregularity in the resistance of the spark of an oscillatory discharge would tend to make the curve representing the current in such a discharge very irregular and different for different electrical conditions The photographs show that capacity tends to separate the oscillations from one another by a dark space which is often

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as wide or even wider than the bright spaces which are supposed to represent the period during which the current flows. This bright space however may not be the exact measure of the time during which the current flows for the particles made luminous by the flow of current remain so for a short time after the current has ceased to flow and thus the actual timeduring which the current flows is less than is indicated by the width of the bright line. The curve representing the flow of current in an oscillatory discharge with large capacity would differ greatly from a simple sin curve and would appear as represented in figure I,

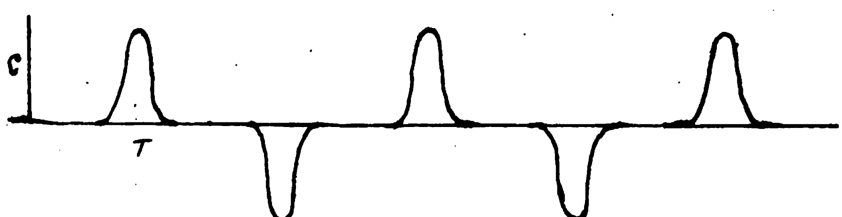


Fig. I

Self-induction tends to counteract the explosive effect of capacity and the oscillations in a spark with much self-induction are not distinct but gradually shade

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into one another making its appearance somewhat like that of an arc fed by an alternating current The curve representing the flow of current in such a discharge would very closely resemble a simple sin curve and the period is very likely that given by the formula

Since the oscillations are not sharply defined it is difficult to verify this conclusion by experiment. Upon the form of discharge current depends to a great extent the nature of the spark. Use will be made of the natureof the dissharge current when we come to discuss the widening of the spectral lines.

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The Cause of Luminosity in the Spark.

The intensity of the light in the spark is intimately connected with the density of the vapor which emits it and it is my purpose to use this relation between the intensity of the lightand density of the gas as a means of explaining the luminosity in the spark.

The older experimenters working upon the idea that the gas conducts like a metalic conductor assume that the light is due to heating caused by the flow of current. Later researches however, indicate that the gas does not conduct like a metalic conductor dut that the charge is transported through it by small particles variously known as ions, electrons and corpuscles and that the light is due to the impactor bombardment of the molecules of the gas by these charged particles.

That the spark does not conduct like a metal is shown by the following experiments. Kaufman[1] compared the resistance of the spark calorimetically with that of a liquid resistance and finds that their ratio does not remain

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I, Weid. Ann. LX. P. 653, I897.

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constant for different potentials and thus different current densities, but that the heat developed in the spark increases much more rapidly than that developed in the resistance when the potential is raised and that the more volatile the electrodes, the more marked the heating in the spark. Likewise Poggendorff[1] found that other things remaining constant the heat developed between lead electrodes was about twice that developed between platinum or iron electrodes which shows that the greater the amount of vapor present in the spark the greater the heat developed. If the gas conducted like a metal we would expect that the more dense the gas the better it would conduct yet the above experiments of Kaufman and Poggendorff show that the reverse is the case.

J. J. Thomsen[2] explains the spark phenomenon by assuming that there are always present in the gas of the gap some charged particles whose motion is directed by the potential gradient and that these particles if the potential gradient is great, acquire sufficient velocity to ionize

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1, Pogg. Ann. 94, P. 632, 1855.

2, Phil. Mag. 5, 50 P. 278, 1900.

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the gas molecules with which they colide. When the ions acquire this ionizing velocity there will be a sudden increase of ions which will result in a sudden transportation of the charge. If the charge is thus transported any gas over and above the amount necessary to carry the current would become a hinderance to its passage and thus an increase of density would raise the resistance and cause a greater heating.

The above assumption regarding the transportation of charge is also in agreement with the light phenomenon of the spark. Plucker and Hittorf found that an increase of the capacity in the circuit caused the lines in the spectrum of Giesler-tubes to increase in brilliancy and width. they ascribe this phenomenon to an increase in trmperature. in considering the form of the discharge current we found that capacity increased the abrubtness of the sparkand it will be shown when we consider the effect of an explosive discharge upon the appearance of the lines that the more abrubt or explosive the spark the denser will be the radiating gas. Thus an increase of capacity has the sameeffect as

I, Phil. Trans. I55, P. I, I865.

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an increase of density. More direct evidence that the luminosity is a function of the density of the gas is given by Shuster and Hemsalech[1] who made some determinations of the speed of the metalic vapor in the spark and conclude that this speed is very great. In their experiments they found that the greater part of the light in the spark comes from the regions where the vapor is most dense. Thus for instance in a spark with little inductance the light comes mostly from near the electrodes, while self-induction which tends to create a metalic arc, causes a uniform distribution of the light emitting particles throughout the spark. This is in accord with the work of Angstrom[2] who found that the more limited theconditions for the appearance of vapor in the spark the less the luminosity. Hartley[3] also found that in the spark the luminosity increases with density of the luminous gas. In the case just mentioned we have to do with the light emitted by the metalic vapor from the

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I, Phil. Trans. I93, P. I89, I889.

2, Phil. Mag. 9, P. 327, I855.

3, Proc. Roy. Soc. 49, P. 448, I89I.

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electrodes which is different from the previous case where the light was emitted by the gas in the spark previous to the discharge. Where the light under consideration is emitted by the metalic vapor from the electrodes the luminosity becomes dependent upon the rate of volitalization of the electrodes and of the distribution of this vapor in the gap. Thus if we increase the capacity in the circuit the luminous volitalized vapor will, on account of the abruptness of the discharge, be restricted to the field near the electrodes where it will be very dense.

A very recent article showing the dependence of the light upon the density of the vapor is that of Weintraub[1] who from his experiments concludes that the luminousity in the mercury arc depends upon the amount of vapor present, over and above that necessary to carry the current, and that when there is only enough vapor present to carry the current there is no light emitted.

In theabove experiments the intensity of the light always increases with an increase in the density of the gas and an increase in the current. If we assume that the

I, Phil. Mag. 6, 7, P. 5, 1904.

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charge is transported from one electrode to another by means of rapidly moving charged particles we have a probable means of explaining the luminosity in the spark, for these particles on collision with the molecules might by their translatory motion impart vibratory motion to the molecules and thus cause light radiations to be emitted. The luminosity would then depend upon the number of impacts or upon the relative number of ions and molecules. Thus under ordinary circumstances an increase of the current or the density of the gas would cause an increase in the luminosity which is in agreement with the above experiments. Yet as shown by Weintraub cases may arise where the increase of current might by increasing the ionization deminish the number of molecules of gas so that the impact between them and the ions might decrease and thus decrease the luminosity. This would however only occur when the supply of gas is very limited; for experiment shows that at ordinary pressures only a small part of the gas is active in carrying the current.

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"idening of the Lines in the Spark Spectrum.

The widening of the lines in the spark, as well as in the arc and flame, has been variously ascribed to ganges pressure, density, temperature of the gas and electrical conditions no one of the explainations suffices for all cases. It is very probable however that there is some condition of the spark that is always present when widening occurs, and that the pressure, density , and electrical conditions only effect the widening in so far as they bring about this condition. The following experimental data on the spark show that the widening of the lines in the spark-spectrum is a function of the abruptness of the discharge. That is, any condition that will tend to bring about a form of discharge current like that shown on page eleven will tend to widen the lines.

An experiment which by its authors is thought to point to the nature of the discharge as the cause of the widening is that of Stern and Lee[1]. They found that a sealed tube with nitrogen at a pressure of two millimeters gave

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I., Proc. Lit. and Phil. Soc. Liverpool, P. 28, 1857.: Phil. Mag. II, P. 406, 1873.

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them sharp lines while another with gas at a slightly greater pressure gave them wide lines. When both tubes were placed in series both gave wide lines. When the sealed tube which contained the nitrogen at a pressure of two millimeters was connected in series with a tube containing nitrogen at atmospheric pressure it gave wide lines butwhen the tube containing nitrogen at atmospheric pressure was connected with a receiver and exhausted the lines of the spectrum in the sealed tube became sharper and sharper as the pressure in the other tube decreased, As far as is known no change took place in the tube whose spectrum was under consideration except a change in the discharge which was constantly decreasing in explosiveness as the pressure of the one tube decreased.

Caillitet[1] experimented with the spark in oxygen and hydrogen at pressures ranging from one to fifty atmospheres and found that the lines became wider as the pressure was increased. Likewise Angstrom[2] found that all grades of spectra from the continuous to a sharp line hydrogen spectrum are obtained by varying the pressure and concludes that it

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I, C. R. 74, P. 1282, 1872. 2, Pogg. Ann. 94, P. 141 1855.

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is the pressure that causes the widening in the lines. when the pressure is changed the potential gradient and form of discharge are also changed for an increase of material in the spark, as is well known, causes a marked rise in the initial resistance of the spark so that the potential necessary to spark will be much greater which will increase the quantity of electricity that must pass during a certain time.

A more direct proof that the nature of the discharge effects the width of the lines is given by Mackhoven[1]. He constructed a tube in such a way as to have two discharges from distinct circuits occur in it simultaneously. With this tube he found that when he had a large capacity in one circuit he got two distinct spectra one with sharp lines from the circuit with small capacity and one with wide lines from the circuit with large capacity. That the increase of capasity effects a widening of the lines is also shown by Plucker and Hittorf[2]. They notice that the lines widen and the general back ground of the spectrum becomes more intense as the

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I, C. R. 95, P. 378, I882.

2, Phil. Trans. I55, P. I, I865.

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pressure is increased and that addition of capacity has the same effect as an increase of pressure. They ascribe the widening of the lines to increase of temperature. We do not know at present whether an increase of capacity means an increase in the temperature of the spark or not, but it is well known that increase in capacity tends to make the spark disruptive.

Hemsalech found that with sufficient self-inductance he could obtain sharp hydrogen lines in hydrogen at atmospheric pressure which agrees with the results obtained by Hale[2] who found that increasing the inductance had the same effect upon the lines as decreasing the pressure. Kirchhoff[3] finds that by placing a wet string or much self-induction in series with the spark it spectrum assumes the character of a flame spectrum. Schenck found that placing self-induction in the sparking circuit reduces the suddenness of the spark. The capacity spark is easily distinguishable from

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I,J. de. Phys. 3, Vol. 9, P. 437, 1900.

2, Astrophysical J. I7, P. I54, 1903.

3, Behandelung der K. Acad. Berlin, P. 73, I86I.

4, Astrophysical, J. I4, II6, I90I.

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that of self-induction for it has a sharp explosive character which the spark in a circuit containing much self-induction does not possess. This explosive character of the spark is not a function of the capacity alone but depends as well on the density and thus upon the pressure of the gas between the electrodes. In the previous experiments it will be noticed that in all cases where the lines widen either the capacity or the density of the gas is increased and where the lines become sharper the density and capacity were reduced or their effect deminished by the insertion of self-induction. The more sudden the heating in the spark the greater the pressure will be. According to J.J. Thomson's computation this pressure is often more than six hundred atmospheres. Such a pressure would be sufficient to cause a violent explosion in the spark gap at every discharge and the luminous particles would be moving to and from the gap with great velocity. We might thus expect to get a widening of the line due to the Dopler effect.

It is thought by many that the period of the particles is in some way dependent upon the density of the gas.and thus that an increase of density causes an increase in the width of the line. This may be the case in the spark

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for in an explosive discharge the heating is so sudden that the heated gas has not time to expand and thus the density of the gas from which the radiations take place is about the same as the density of the gas in the gap before the spark occured. In the cases where the discharge is gradual the heated gas would have an opportuniny to escape from the gap and this the gas from which most of the light is radiated would be much more attenuated than in the case of the sudden spark. This consideration however only refers to cases like the discharge in a Geisler-tube where the light whose spectrum is considered is emitted by the gas present between the electrodes before any spark occured. In the case where the spectrum is that of the luminous metalic vapor of the electrodes the increase of capacity would increase the amount of this vapor for it is well known that an increase in capacity causes an increase in the disintigration of the electrodes. An increase in the suddenness of the sparkdue to capacity would also increase the density of the radiating gas since the more sudden the spark the less time would be given the newly volitalzed vapor to ex-

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pand and thus in an explosive discharge the light would be emitted by this vapor while it was still in a very dense layer about the electrodes. If the width of the spectral lines is a function of the density of the radiating gas, then according to the above consideration the increase of the capacity or of the abruptness of the spark would cause a widening in the lines in the spectrum in the case where the spectrum under consideration is that of the metalic vapor from the electrode as well as in the case where it is the spectrum of the gas originally in the gap. This is in agreement with the experimental results.

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